AD-A044 766 COLD REGIONS RESEARCH AND ENGINEERING LAB HANOVER N H F/G 13/11
FREEZING RISK FOR WATER MAINS IN FROZEN GROUND (UNDERSOKNING AV--ETC(U)
SEP 77 L JANSON
UNCLASSIFIED CRREL-TL-644 NL

Draft Translation 644
September 1977

12



# FREEZING RISK FOR WATER MAINS IN FROZEN GROUND

L.E. Janson





CORPS OF ENGINEERS, U.S. ARMY
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

| REPORT DOCUMENTATION PAGE | | READ INSTRUCTIONS BEFORE COMPLETING FORM |
|---|---|---|
| 1. REPORT NUMBER<br>Draft Translation 644 | 2. GOVT ACCESSION NO. | 3. RECIPIENT'S CATALOG NUMBER |
| 4. TITLE (and Subtitle)<br>FREEZING RISK FOR WATER MAINS IN FROZEN GROUND | | 5. TYPE OF REPORT & PERIOD COVERED |
| | | 6. PERFORMING ORG. REPORT NUMBER |
| 7. AUTHOR(s)<br>L.E. Janson | | 8. CONTRACT OR GRANT NUMBER(s) |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>U.S. Army Cold Regions Research and Engineering Laboratory<br>Hanover, New Hampshire | | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS |
| 11. CONTROLLING OFFICE NAME AND ADDRESS | | 12. REPORT DATE<br>September 1977 |
| | | 13. NUMBER OF PAGES<br>16 |
| 14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) | | 15. SECURITY CLASS. (of this report) |
| | | 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE |

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

FROZEN GROUND--SWEDEN
PIPES
INSULATION

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

In the autumn of 1971 an experimental plant was installed at Forslunda waterworks, Umea. The purpose was to verify experimentally the risk for freezing of insulated and uninsulated asbestos-cement pipes according to theoretical calculations regarding laying depth ~~contr~~ versus frost penetration depth.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

14 CRREL-TL-644

DRAFT TRANSLATION 644

6

ENGLISH TITLE: FREEZING RISK FOR WATER MAINS IN FROZEN GROUND

FOREIGN TITLE: UNDERSOKNING AV FRYSRISKEN FOR VATTENLEDNINGER OVANFOR TJALGRANSEN.

10 Lars-Eric

AUTHOR: ~~L.E.~~ Janson

11 Sep 77

12 19p.

21

Trans of

~~SOURCE~~: Oslo, Frost i jord, nr 14, October 1974, p.59-67.

(Norway) n14 p59-67 oct 74,

Translated by Sam Blalock, Kingsport, Tennessee for U.S. Army Cold Regions Research and Engineering Laboratory, 1977, 16p.

NOTICE



037 100

# THE FREEZING RISK FOR WATER MAINS IN FROZEN GROUND

By: Professor Lars-Eric Janson

## Introduction

Beginning with the computational methods given in publications (1) and (2) in the compilation below, VBB Vattenbyggnadsbyran conducted research in Autumn 1969, under a Commission from AB Eternitror, Varberg. The result was the "Instructions for Computing the Laying Depth of Double Eternit Pipes with an Intermediate (space) Insulation of Polyurethane Foam". In the Autumn of 1971 VBB was requested to establish a program with descriptions for an experimental plant for field studies of the freezing risk for a water main insulated as indicated above.

Compilation in the introduction:

1. Janson, L. E. (1968), Tjaldjupet i Sverige. (Frost Depth in Sweden), Information from the State Natural Conservation Department, SNV, V4.

2. Janson, L. E. (1969), Laggningsdjup for vattenledningar. (Laying Depth for Water Mains), Publication of the Swedish Water and Drain Association, VAV, P14.

3. VBB Research as given above, dated 3 November 1969.

## Purpose

One purpose was experimentally to pin-point the risk of freezing for insulated and uninsulated Eternit pipes according to (1) and (2). Another purpose was to check on the validity of the general calculation found in (3). The study was mainly concentrated on verifying equations 1 and 2 in (2).

$$Q'/L = \frac{1{,}75\,A}{C \ln \frac{\vartheta_{be} - \vartheta_h}{\vartheta_{en} - \vartheta_h}} \qquad 1$$

$$Q'/L = \frac{1{,}75\,B/(1 + B/A)}{C \ln \frac{\vartheta_{be} - \vartheta_h}{\vartheta_{en} - \vartheta_h}} \qquad 2$$

where

$$A = \lambda/\ln\,(2\,h/r_{iu}) \qquad 3$$

$$B = \lambda'/\ln\,(r_{iu}/r_{ii}) \qquad 4$$

$$\text{is } \vartheta_h = -\,G'(\xi - h) \qquad 5$$

All of the symbols have the same meaning as in (2), namely:

$C$ = the specific heat of the water, kcal/kg$^{\circ}$C

$G'$ = the ground temperature gradient, $^{\circ}$C/m

$h$ = the laying depth computed to the center of the pipe, $h = H$ in (3)

$L$ = length of main, km

$Q'$ = daily mean during the winter season for flow in the main, l/s

$r_{ii}$ = the internal radii of the insulation, m

$r_{iu}$ = the external radii of the insulation, m

$r_u$ = the external pipe radius, m

$\vartheta$ = temperature, $^{\circ}$C

$\vartheta_h$ = the ground temperature at the depth of the main without the effect of the heat released by the main, $^{\circ}$C

$\vartheta_{be}$ = the water temperature at the main intake, $^{\circ}$C (main temperature of the mixed water in a cross-section of pipe)

$\vartheta_{en}$ = water temperature at the main outlet, $^{\circ}$C (mean temperature in the mixed water in a cross-section of pipe)

$\vartheta_{oe}$ = the extreme winter value of the sine curve which has a symmetrical axis, with the mean annual temperature, includes a cold mass between the frost line and that part of the sine curve which runs below this line (mean annual temperature for Umea is +3.1$^{\circ}$C)

$\vartheta_t$ = water temperature in the pipe crown

$\lambda$ = heat conductivity index for the type of soil, kcal/mh$^{\circ}$C

$\lambda'$ = the heat conductivity index for insulation, kcal/mh$^{\circ}$C

$\xi$ = frost depth without the effect of the heat releasing flow in the water main, $\xi = H_0$ in (3).

According to the international system of units (SI) the heat conductivity number is given in W/mK and the specific heat in Ws/kgK. The following are valid for computation:

$$1 \text{ kcal/mh}^{\circ}\text{C} = 1.16 \text{ W/mK}$$
$$1 \text{ kcal/kg}^{\circ}\text{C} = 4\,190 \text{ Ws/kgK}$$

## Experimental Plant

The experimental plant, which is located at the Forlunda Waterworks in Umea, has been set up according to the program and descriptions in all essentials. Thus two parallel Eternit NT10 pipe mains 200 mm in diameter, and 106 m long, were buried 50 cm deep, measuring to the pipe center. One of

the mains was insulated with cellular plastics (polyurethane), protected against humidity and mechanical damage by an outer pipe with a diameter of 300 NT 7.5. The pipes are 5 m apart. At each pipe intake and outlet sensors were installed to record the intake and discharge of water, as well as to read the temperature gauges. Sensors for temperature gauges were mounted in a measuring section 3 m from the end of each pipe, and frost meters were also placed there. The position of the meters and their designations can be seen in the apparatus plan, Figure 1.

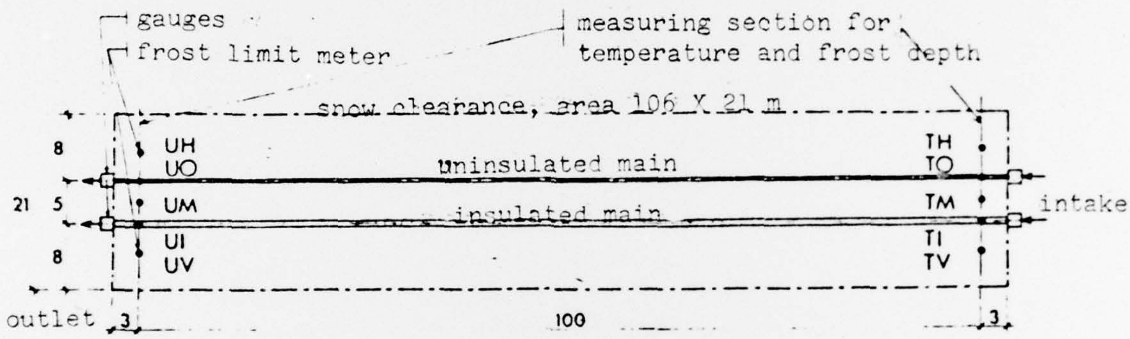


Figure 1. Plan of experimental plant.

The main symbols chosen for the measuring points are TO (inflow, uninsulated main), UO (discharge, uninsulated main), TI (inflow, insulated main) and UI (discharge, insulated main). An area of about 21 X 106 m remained free of snow throughout the Winter.

Temperature gauges were placed both inside and outside the pipes, as can be seen in Figures 2, 3, 4 and 5. The gauges are 100 mm long and 10 mm in diameter, and are of the same resistance type as used in (1), i.e., are made of a copper coil with $R_0 \approx 35$ ohms at $0^{\circ}C$. The same measuring bridge and the same calibration method was also used, meaning a maximum error of $\pm 0.1^{\circ}C$ in temperature readings.

The water in the main was taken from the main water line leading to the city (the waterworks with artificial infiltration), at an almost constant water temperature during the Winter of about $+5.5^{\circ}C$ in the inlet to the experimental plant. After passing into the plant, the water is conducted to an infiltration tank situated downstream.

The ground within the area consists of a layer of homogeneous, somewhat silty sands, in contact with the heaters. Sight analyses of the sample (translator's note: literally, ore) measuring sections show little variation. The water retaining capacity of the ground with free drainage amounts to about 6% by weight of the dried substance. The mean dry density in the main ditches was measured with a cylinder volume meter after they were filled in and was about $1.4\ t/m^3$. According to (1) (Figure 3.4.2 and Figure 3.4.1, reproduced as Figure 6) the heat conductivity index for the frozen ground is 0.7 kcal/m $h^{\circ}C$ and is 0.5 kcal/m $h^{\circ}C$ for unfrozen ground.

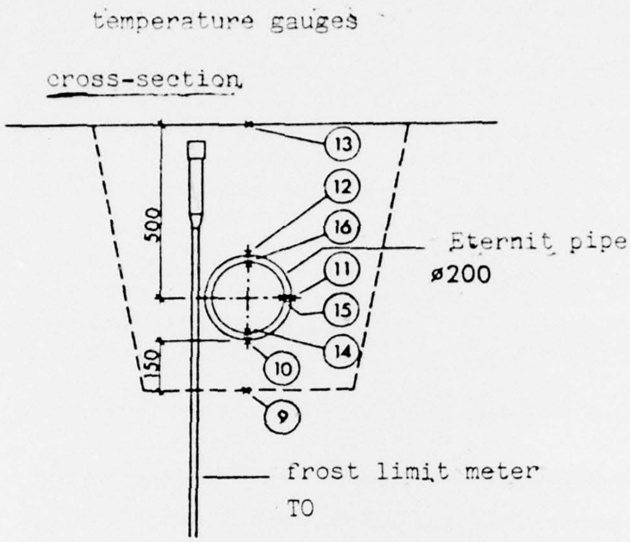


Figure 2. Intake, uninsulated main (TO). Placement of temperature gauge and frost limit meter.

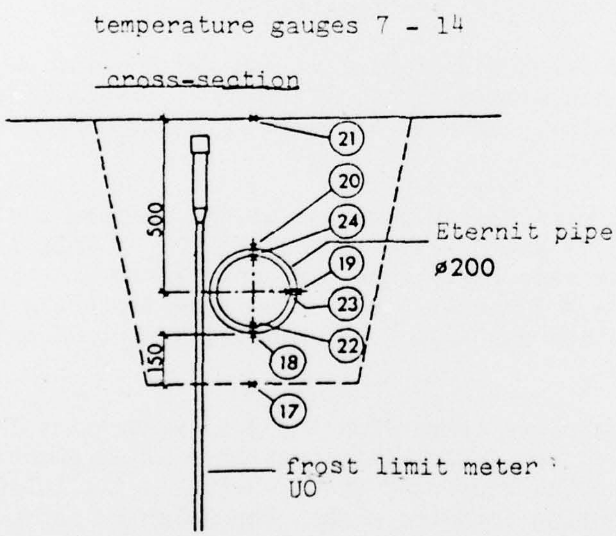


Figure 3. Outlet, uninsulated main (UO). Placement of temperature gauges and frost limit meters.

temperature gauge NR 1-8

cross-section

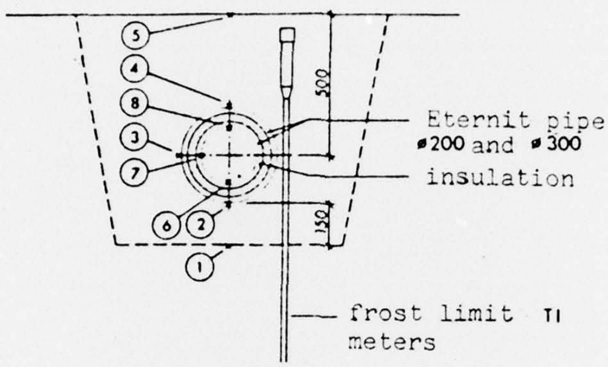


Figure 4. Intake, insulated main (TI). Placement of temperature gauges and frost limit meters.

temperature gauge NR 25-35

cross-section

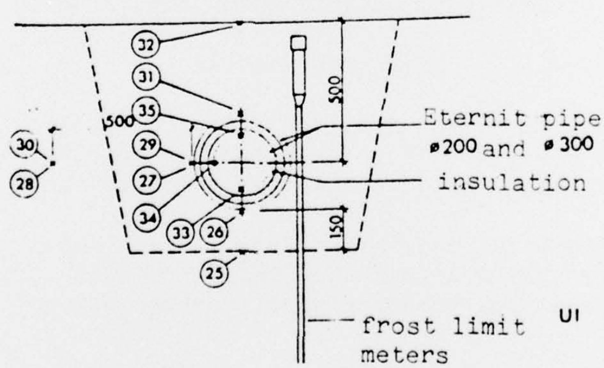


Figure 5. Outlet, insulated main (UI). Placement of temperature gauges and frost limit meters.

All ground levels significant for the measurement were calibrated and related to the common reference plane of the means running through the centers of the pipes. Both the means and the ground surface above inclined 10 cm from the intake, meaning a constant flow level along the entire measuring section.

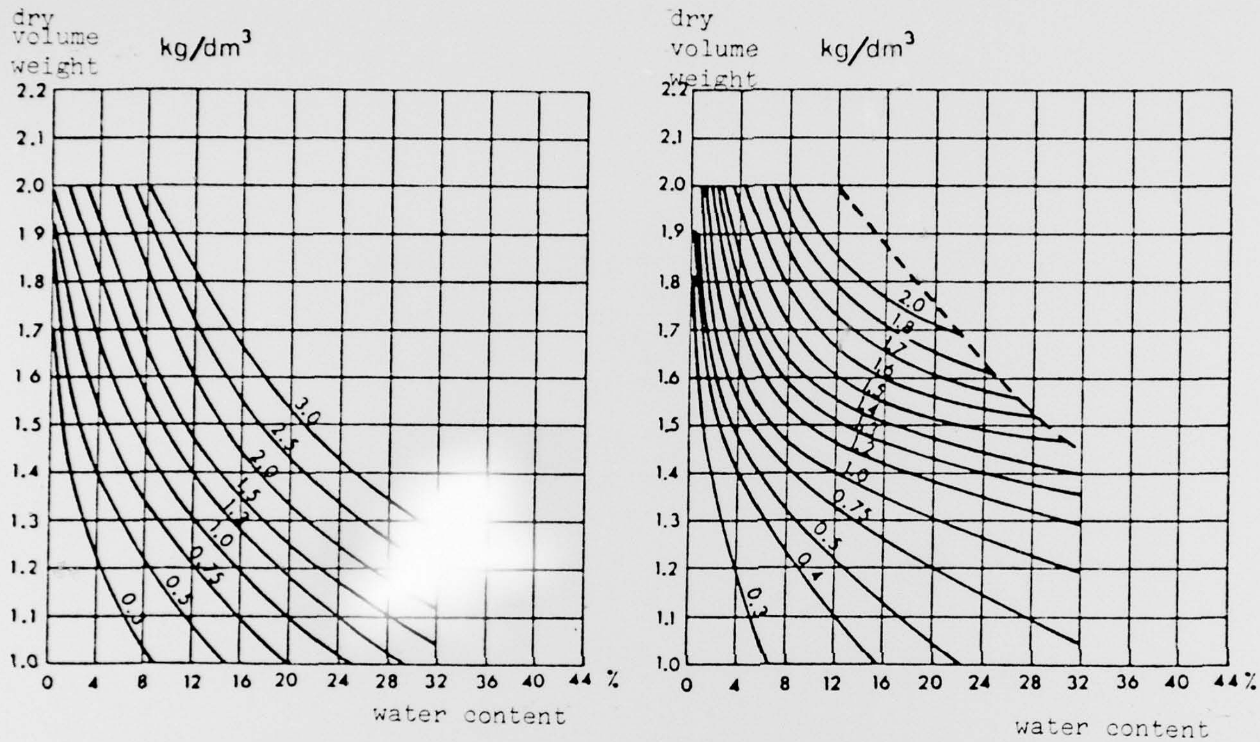


Figure 6. Heat conductivity index according to (1).

## Research Results

The experimental plant was built in October 1971 and started up for the Winter season on 22 November 1971. Research was continuously conducted until 15 May 1972, with special shutdown research conducted on 3 - 8 March 1972.

Frost limit meters and the water (flow) meters were read once a week, at which time snow clearance was checked. The air temperature and the atmospheric humidity were obtained from the waterworks through automatic recording with a thermograph.

All measured values were processed. In view of the air temperature, whose distribution in time is shown in Figure 7, one can state that the Winter of 1971 - 1972 must be considered fairly normal in regard to the amount of cold. Thus the amount of cold amounted to 1060°C days; while the mean or maximum amount of cold at Umea amounted to 800 and 1600°C-days. However, the fact that the Winter was not especially cold did not play a significant role for research purposes since the laying depth was set with exceptional moderation simply to protect against a milder research winter, i.e., to 50 cm measured from the surface of the ground to the center of the pipes.

The extent of snow cover outside the research area is given in Figure 7. The amount of snow during the research Winter can be considered quite normal.

The frost depth within the measurement section area at the intakes and outlets is shown in Figure 8 for the uninsulated mains and in Figure 9 for the insulated mains. The figures also show the time variation in water flow in the mains and the changes in water temperature at the crown of the intake and outlet pipes.

It was of special interest to determine how the heat released by the uninsulated mains at the inlets (TO), where the temperature of the mixed water is above +5°C, can keep the ground under the main frost-free. At outlets (UO), where the temperature of the mixed water is considerably lower because of the cooling of the water during passage through the mains, the frost line is also lowered. This was especially obvious during the shutdown of 3 - 8 March, since the ground under the mains at the outlets rapidly froze down to 1.2 m. The maximum frost line depth within the area of the mains was simultaneously 1.6 m at the outlets (UH) and 1.35 m at the intakes (TH). It can also be established that the heat released for the uninsulated mains quickly thaws the frozen ground both above and below the mains when the flow starts again. This naturally occurs most rapidly at the intakes, because the ground above the mains was frost-free for about a month before the ground outside of the area of influence of the mains (cf. TH) thawed.

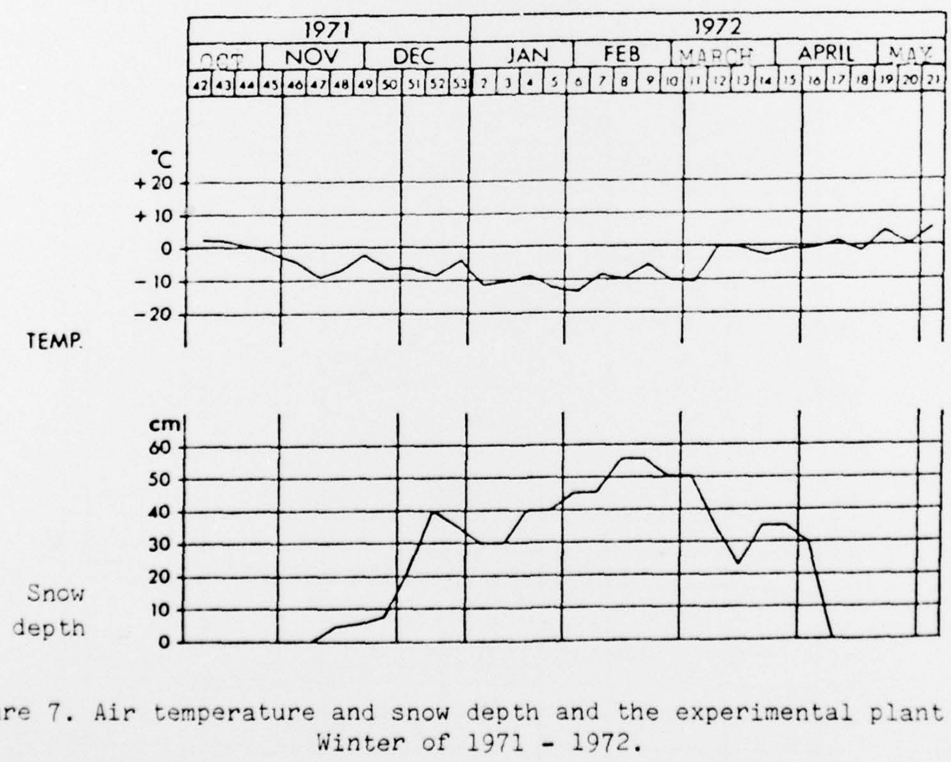


Figure 7. Air temperature and snow depth and the experimental plant in the Winter of 1971 - 1972.

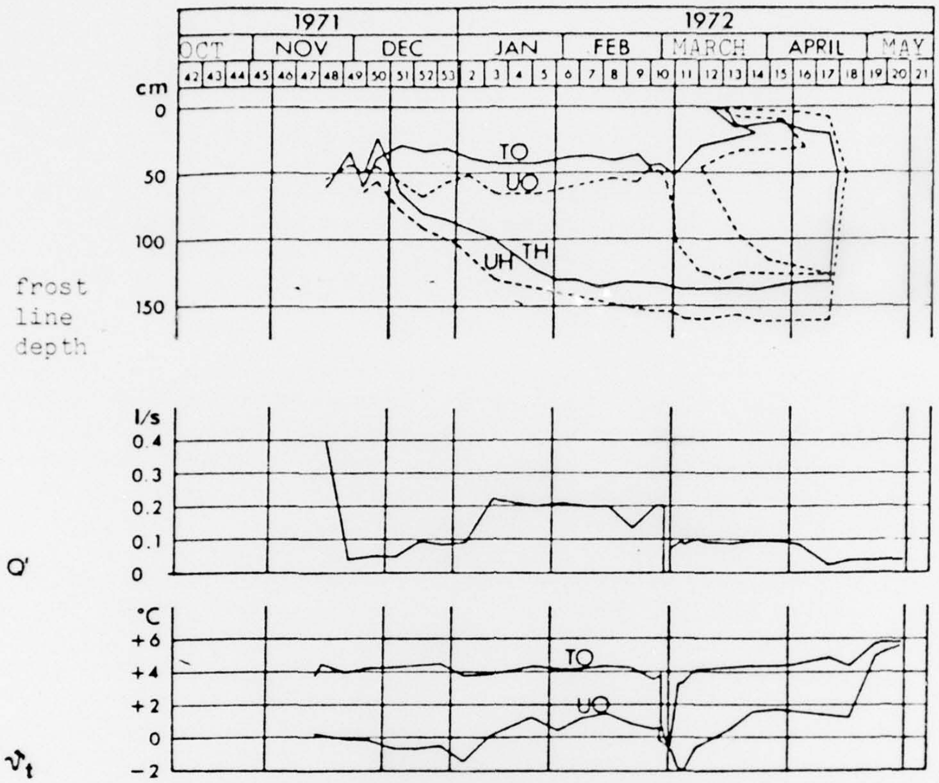


Figure 8. Frost line depth in the main trench at intake and outlet for the uninsulated main (TO) and (UO) respectively outside of the area of influence of the main (TH) and (UH).

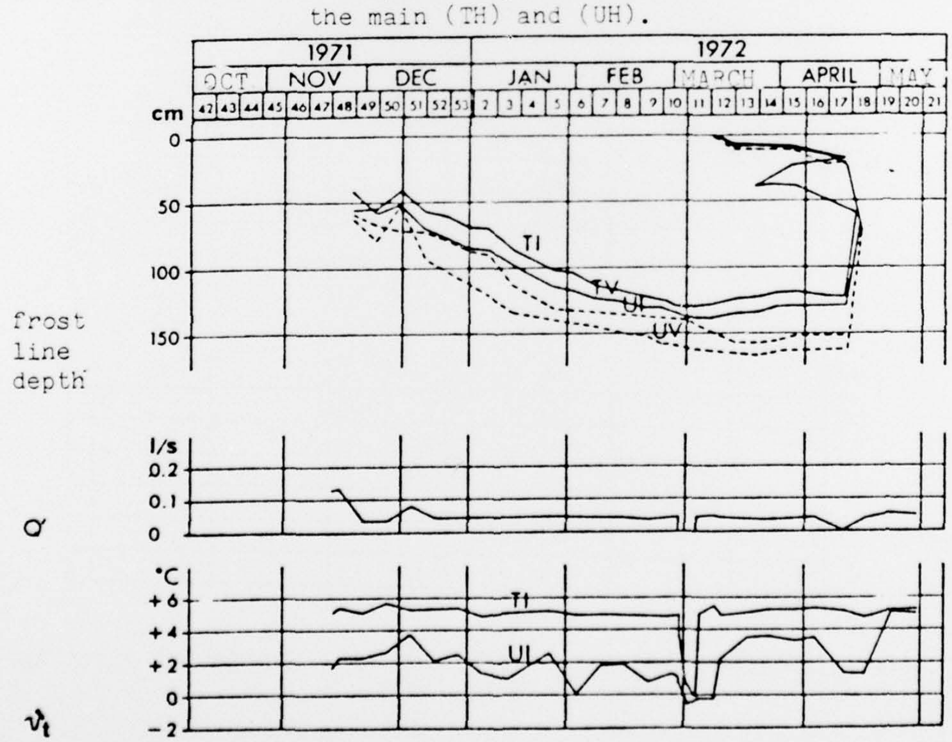


Figure 9. Frost line depth in the main trench at intake and outlet for the insulated main (TI) and (UI) respectively outside of the area of influence of the main (TV) and (UV).

As expected, the heat released from the insulated main was extremely slight, which means that the ground under the main freezes to almost the same level as the ground outside the area of influence of the main. Here there is no great difference between the intakes and outlets until the April thaws, when the ground melts somewhat faster above the intakes (TI) than above the outlets (UI).

As already indicated in (2), the research shows that heavy insulation of a water main can be used only where the risk of frost dislocation does not exist, i.e., in rocks and where the soil is not moved by the frost. On the other hand, it is exactly in this case that the frost line is deepest, so that a great deal is to be gained by insulating such stretches of line. In this connection insulation appears to be especially advantageous during shutdown, as is clearly shown by the research. Despite the fact that the ground around the insulated main is completely frozen to a great depth at the beginning of the shutdown, the line was able to remain without flow for over 5 days without any measurable ice formation (measured by the pressed water volume) being indicated. On the other hand, in the uninsulated mains, where the ground was frost-free beneath the main at the beginning of the shutdown, meaning a buffer against freezing, ice formation in the line could be detected after only 10 hours, and after 2 days about 2% of the pipe section was filled with ice, with the formation of ice in the top part of the pipe. It should be noted that there was main tolerance for a pressure increase after the surplus water had been raised to the top for measuring. If freezing had occurred in a main between shut valves, the main would naturally have burst or the rubber gaskets in the joints would have failed.

As additional illustrations, $0^{\circ}$-isotherms in the measuring sections at the intakes and outlets have been established for some different points of time in Figures 10, 11, 12 and 13 using temperature measurements made in the ground around the pipe and the results from the maximum frost measurement.

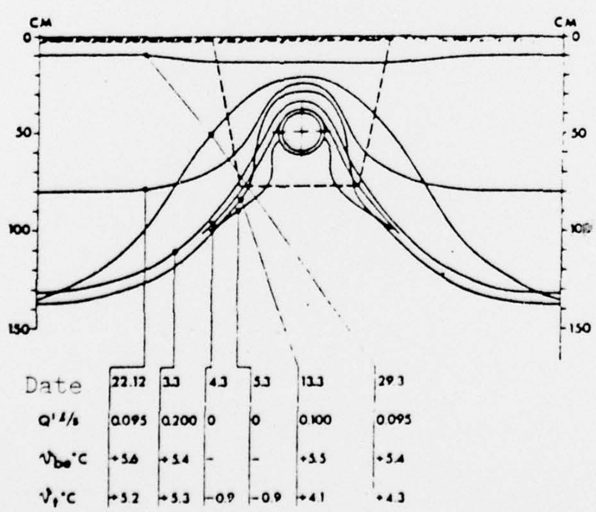


Figure 10. Intake, uninsulated main (TO). Isotherms for $0^{\circ}$C.

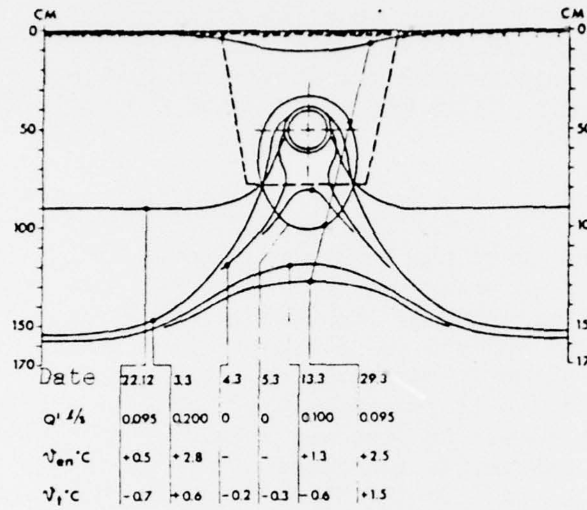


Figure 10. Outlet, uninsulated main (UO). Isotherms for $0^{\circ}C$.

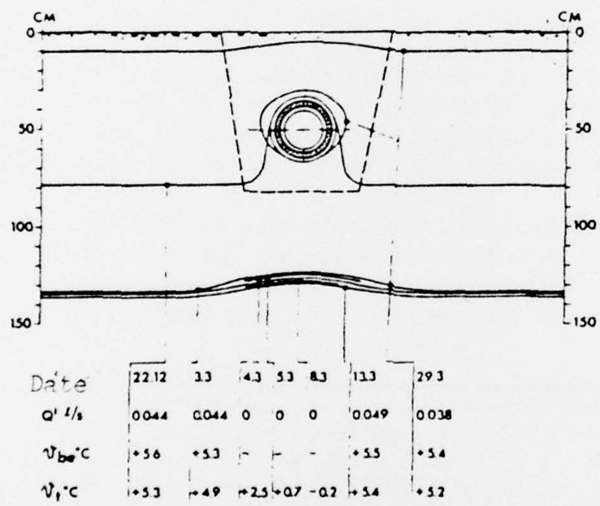


Figure 12. Intake, insulated main (TI). Isotherms for $0^{\circ}C$.

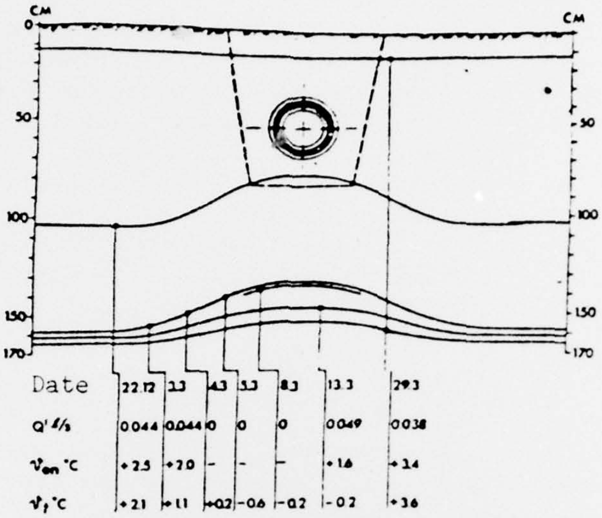


Figure 13. Outlet, insulated main (UI). Isotherms for 0°C.

## Evaluation

With the aid of the measured values for frost depth $\xi$, ground temperature $\vartheta_h$ and water temperature at the intakes $\vartheta_{be}$ and outlets $\vartheta_{en}$, equations 1 and 2 can now be checked by computing the flow $Q'_{ber}$. This calculated value, $Q'_{ber}$, is then compared with the measured value $Q'_{matt}$. For this purpose a check computation was made on 9 February 1972, 3 March 1972, 13 March 1972, and 29 March 1972, from which 3 March 1972 can be considered as representative of the most severe Winter conditions. In accordance with the computations it is natural to use this condition to set the dimensions for the entire Winter, which gives a value on the safe side for the rest of the Winter, with reference to the demand for the least necessary flow. It may be added that it is quite normal for the greatest risk of freezing to occur at a point in time shifted to about 6 weeks after the coldest time of the year, indicated by air temperature on the ground surface.

The values from 3 March 1972 will be treated before the rest of those mentioned above. These measurements gave $\xi_{med}$ = 1.5 m, $\vartheta_h$ = -7.3°C (temperature gauges 28 and 30, $\vartheta_{oe}$ = -11°C (see Figure 5.2.1 in (1) ) along with $\vartheta_{be}$ = +5.4°C, $\vartheta_{en}$ = +2.8°C, $Q'_{matt}$ = 0.200 l/s for the uninsulated mains and $\vartheta_{be}$ = +5.3°C, $\vartheta_{en}$ = +2.0°C and $Q'_{matt}$ = 0.044 l/s for the insulated mains. With this value entered in equation 1 and with L = 0.1 km and $\lambda$ = 0.5 kcal/m h°C (the ground taken as unfrozen) $Q'_{ber}$ = 0.181 l/s was obtained for the insulated main, which should be compared with $Q'_{matt}$ = 0.200 l/s. For the uninsulated main, according to equation 2 with $\lambda$ = 0.7 kcal/m h°C (the ground is frozen) $Q'_{ber}$ = 0.40 l/s, which is to be compared with $Q'_{matt}$ = = 0.044 l/s. In both cases (see Table I) exact correspondence was found with the measured values, if the calculated values are increased by 10%. The slight deviation can easily be explained by corresponding inexactitude in determining the heat conductivity index of the ground. For example, complete verification of equation 1 was found for the uninsulated main, if the

heat conductivity index was set at 0.55 kcal/m h°C instead of 0.5, a value which lies completely within the limits of the area of dispersion of the real heat conductivity index in this research. This becomes particularly obvious in consideration of the fact that the ground around the pipes is partially frozen and partially unfrozen (see Figure 6 also).

To a great extent the same results were obtained in consideration of 9 February 1972. Here the measurements were, $\vartheta_h = -6°C$, $\vartheta_{be} = +5.4°C$ and $\vartheta_{en} = 3.0°C$ in the uninsulated main. According to equation 1 $Q'_{ber} = 0.175$ l/s, while $Q'_{matt} = 0.200$ l/s. Where $\vartheta_{be} = +5.2°C$ and $\vartheta_{en} = +2.3°C$ for the insulated main, according to equation 2 we get $Q'_{ber} = 0.041$ l/s and $Q'_{matt} = 0.043$ l/s.

With $\vartheta_h = -5.5°C$, $\vartheta_{be} = +5.5°C$ and $\vartheta_{en} = +1.3°C$, the control calculations for 13 March 1972 give $Q'_{ber} = 0.086$ l/s for the uninsulated mean according to equation 1. In this case $Q'_{matt} = 0.100$ l/s, and it is noteworthy that the difference between the calculated and the measured values are of the same order of magnitude as before. This, considered as a systematic error, supports the error assumed earlier in the presumption of the magnitude of the heat conductivity index. For the insulated mean $\vartheta_{be} = +5.5°C$ and $\vartheta_{en} = 1.6°C$. In this case equation 2 gives $Q'_{ber} = 0.028$ l/s, while $Q'_{matt} = 0.049$ l/s. This great deviation between the calculated and the measured values is disappointing at first. A closer analysis, however, seems to show that the stationary condition on 13 March had not yet changed 5 days after shutdown from the interruption on 8 March. The shutdown for the uninsulated main lasted only 2 days and was interrupted on 5 March. If this should be the cause of the deviation between the calculated and measured value of the flow, then a control calculation made later should give better results.

For this reason the conditions on the insulated main were checked on 29 March 1972. Equation 2 gave $Q'_{ber} = 0.033$ l/s, while $Q'_{matt} = 0.038$ l/s, with $\vartheta_h = -1°C$, $\vartheta_{be} = +5.4°C$ and $\vartheta_{en} = +3.4°C$. It is obvious that the agreement is now considerably better.

Table I
Measured and Computed Values

| Research | Insulated Pipe | | | | | | | Uninsulated Pipe | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | frost line depth m, $\xi_{med}$ | ground temp. $\vartheta_h$ °C | $\vartheta_{be}$ | $\vartheta_{en}$ | $Q'_{ber}$ | $Q'_{mätt}$ | difference in % | frost line depth m, $\xi_{med}$ | ground temp. $\vartheta_h$ °C | $\vartheta_{be}$ | $\vartheta_{en}$ | $Q'_{ber}$ | $Q'_{mätt}$ | difference in % $Q'_m$ |
| 1972-03-03 | 1,5 | -7,3 | 5,3°C | 2,0°C | 0,040 | 0,044 | 9,1 | 1,5 | -7,3 | 5,4°C | 2,8°C | 0,181 | 0,200 | 9,5 |
| 1972-02-09 | | -6,0 | 5,2°C | 2,3°C | 0,041 | 0,043 | 4,7 | | -6,0 | 5,4°C | 3,0°C | 0,175 | 0,200 | 12,5 |
| 1972-03-13 | | -5,5 | 5,5°C | 1,6°C | 0,028 | 0,049 | 42,9 | | -5,5 | 5,5°C | 1,3°C | 0,086 | 0,100 | 14,0 |
| 1972-03-29 | | -1,0 | 5,4°C | 3,4°C | 0,033 | 0,038 | 13,2 | | | | | | | |

(Note: commas should be read as decimals.)

## Practical Application

The evaluation of the research shows that the computational principles used earlier were experimentally verified. The calculations carried out in (3) can thus be used for computing dimensions. Here it should be stressed that these calculations presume a less favorable filling around the pipes than what is valid for the research. Thus a filler with a heat conductivity index of 1.6 kcal/m h°C is used as a certainty, as opposed to the 0.5 - 0.7 kcal/m h°C in the research. This means that if the insulated mean has been designed according to (3) and presuming that $\xi = H_0 = 1.5$ m, the necessary flow at H = 0.5 m for the coldest part of winter remains 0.141 l/s (see Table II, an excerpt from the tables in (3) valid for silty sand, which corresponds to clay according to (2) ). Here the temperature gradient should have been 0.5°C at the highest calculated from the intake of the main to its outlet. If a 4 times greater temperature gradient is permitted, or 2°C, a flow of about one-fourth of the values in the tables or about 0.035 l/s is necessary. This value is of the same order of magnitude as that measured in the research (3 March 1972), despite the more favorable back-filling material used around the research main. Still, the difference in the results was affected more by the fact that the tables for silty sand were made with the general assumption that the temperature gradient G' in the ground is 5°C/m (4°C/m in sand and 10°C/m in clay). Here in the general case of the calculation made according to equation 5, the lowest value for $\vartheta_h = -5°C$, while in the research it was $\vartheta_h$ = =7.3°C. In addition the water temperature at the intake is about +5°C in the research, while in the general computations the water temperature is assumed to be +0.5°C at the intake and 0°C at the outlet.

It is also clear from the above that in the research G' = 7.3°C/m, i.e., G' is a value that lies between those valid for sand and for clay. Since the silty sand in this case has an unusually low density and thus a low heat conductivity index, this is completely natural.

In regard to the shutdown in the insulated main, it is enough in this connection to state that the shutdown in a practical case never has a dimensional connection with the choice of the laying depth. This is also clear from the computational tables in (3) (see Table III, excerpt from the tables in (3) ).

## Conclusion

The freezing research in Umea in the Winter 1971 - 1972 has shown that good prerequisites can be found for essentially shallower laying depth in regard to frost in rock trenches and in ground which is not subject to frost displacement by means of using high quality insulating double Eternit pipes. Good agreement has been found between the calculated and the measured water flows. The theoretical calculations made according to (2) have been satisfactorily verified. In a practical case the calculation can simply be used with the aid of the tables in (3) for computing dimensions.

Table II

Extract from Tables in (3) Showing the Connection Between the Laying Depth H, the Frost Line Depth $H_0$ and the Specific Flow Q'/L

Double Eternit pipe in sand

*Dimension 200 mm, NT 10.0/ 300 mm. NT 7.5*

| HO–H m | H m | Q'/L l/sek. x km |
|---|---|---|
| .50 | .50 | .74 |
| .50 | 1.50 | .71 |
| .50 | 2.50 | .70 |
| 1.00 | .50 | 1.41 1972-03-03 |
| 1.00 | 1.50 | 1.35 |
| 1.00 | 2.50 | 1.33 |
| 1.50 | .50 | 2.09 |
| 1.50 | 1.50 | 2.00 |
| 1.50 | 2.50 | 1.96 |
| 2.00 | .50 | 2.76 |
| 2.00 | 1.50 | 2.65 |
| 2.00 | 2.50 | 2.60 |
| 2.50 | .50 | 3.43 |
| 2.50 | 1.50 | 3.29 |
| 2.50 | 2.50 | 3.23 |
| 3.00 | .50 | 4.10 |
| 3.00 | 1.50 | 3.94 |
| 3.00 | 2.50 | 3.87 |
| 3.50 | .50 | 4.78 |
| 3.50 | 1.50 | 4.58 |
| 3.50 | 2.50 | 4.50 |
| 4.00 | .50 | 5.45 |
| 4.00 | 1.50 | 5.23 |
| 4.00 | 2.50 | 5.13 |

Table III

Extract from Tables in (3) Showing Maximum Values for Distance Between Frost Line Depth $H_0$ and Laying Depth H, in Reference to the Formation of Ice During a 20-hour Shutdown

Double Eternit pipe in sand

*Dimension 200 mm, NT 10.0/ 300 mm. NT 7.5*

| H m | HO–H m |
|---|---|
| .50 | 4.68 1972-03-03/08 |
| 1.50 | 4.88 |
| 2.50 | 4.97 |

*Dimension 200 mm, NT 10.0/ 350 mm, NT 7.5*

| H m | HO–H m |
|---|---|
| .50 | 7.56 |
| 1.50 | 7.76 |
| 2.50 | 7.85 |

continuation of Table III:

*Dimension 250 mm, NT 10.0/ 350 mm, NT 7.5*

| H m | HO–H m |
|---|---|
| .50 | 5.96 |
| 1.50 | 6.27 |
| 2.50 | 6.41 |

*Dimension 250 mm, NT 10.0/ 400 mm, NT 7.5*

| H m | HO–H m |
|---|---|
| .50 | 9.83 |
| 1.50 | 10.14 |
| 2.50 | 10.28 |


## Summary

In the autumn of 1971 an experimental plant was installed at Forslunda waterworks, Umeå. The purpose was to verify experimentally the risk for freezing of insulated and uninsulated asbestos-cement pipes according to theoretical calculations regarding laying depth contra frost penetration depth, reported in the publications "Tjäldjupet i Sverige", Janson, L.-E. – SNV, V4, 1968[1)] and "Läggningsdjup för vattenledningar", Janson, L.-E. – VAV, P14, 1969[2)].

The natural soil within the test area and in the layer affected by the installation consists of sligthly silty sand. Two parallel asbestos-cement pipes, Ø 200 NP 10, length 106 m each, were laid at a depth of 50 cm as measured from the centre of the pipes. The distance between the pipes was 5 m. One pipe was insulated with cellular plastic (polyuretan) which was protected against humidity and mechanical injuries by an asbestos-cement pipe, Ø 300 NP 7.5. The backfill, the natural soil, was sieve analysed and the humidity determined. Water for the two conduits was taken from the waterwork's water main, whereby an almost constant temperature of the water was obtained at the inlets of the pipes. Several sensors to temperature indicators were placed inside as well as outside the pipes within a section of 3 m from the ends of each pipe. Within these sections frost penetration limit meters were placed.

An area of 21 x 110 $m^2$ of the installation was kept clear from snow during all of the winter. Continuous tests were carried out from November 22, 1971 to May 15, 1972, and a flow stop test was carried out during the time March 3-8, 1972.

On the basis of the measurements of frost penetration and water temperature at the inlets and outlets, the reported theoretical calculations in the abovementioned publications were controlled by estimating the water flow, $Q'_{ber}$, which was compared with the value obtained by measurement, $Q'_{\text{mätt}}$. Complete conqruity with the measured values was obtained, when the estimated values were increased by 10 per cent. This small deviation can easily be explained by the corresponding inexactness when determining the coefficient of thermal conductivity.

The evaluation of the test shows that the principles of calculation applied earlier have been satisfactorily verified. By using high-quality insulation for pipes the prospects are good for decreasing the foundation depths considerably with regard to frost penetration in rock excavation and in non–frost–heaving soils. The deepest frost penetration appears in these soils, and thus large cost savings can be obtained. The use of insulated pipes is particularly advantageous at flow stops. This is conclusively shown by the test.

1) "The Ground Frost Depths in Sweden"

2) "Laying Depths for Water Pipes in the Ground with Reference to Frost".